Thermo-Physical Properties of Intermediate Temperature Heat Pipe Fluids

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Abstract. Heat pipes are among the most promising technologies for space radiator systems. The paper reports further evaluation of potential heat pipe fluids in the intermediate temperature range of 400 to 700 K in continuation of two recent reports. More thermo-physical property data are examined. Organic, inorganic and elemental substances are considered. The evaluation of surface tension and other fluid properties are examined. Halides are evaluated as potential heat pipe fluids. Reliable data are not available for all fluids and further database development is necessary. Many of the fluids considered are promising candidates as heat pipe fluids. Water is promising as a heat pipe fluid up to 500-550 K. Life test data for thermo-chemical compatibility are almost non-existent.

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Space Power Heat Rejection Technologies

- Needs higher temperature heat rejection systems: 400 – 700 K considered as an envelope
- Necessity to save on mass and size
- Heat pipes potentially are important components of HRS

Heat Pipe Technologies – Current Status

- Below 400 K

  Ex. : Commercial and space electronics applications – mature technology
- Above 700 K

  High temperature alkali metal heat pipes - technologies exist
- Temperature range 400 – 700 K : Defined as Intermediate Temperature Heat Pipe Technologies

  - Far less developed

Intermediate Temperature Heat Pipes

Current Technology Development Approaches

- Augment the upper operational temperature limit of the ambient temperature heat pipe technology-
  Ex: Water heat pipes
- Develop new technologies for the intermediate temperature heat pipes
  - Heat pipe fluids and compatible metals
  - Wick structures
  - Fabrication technologies

Intermediate Temperature Heat Pipe Fluids

Important characteristics to look for

- Maximum operational temperature should be at least 100 K below the critical temperature
- Must be in fluid phase, i.e., melting point below the operational temperature

A number of halides seems to have the requisite characteristics. Some elements (Ex. Sulfur and Iodine) are also potential heat pipe fluids.

New in the Current Work

Recent Reports

- Anderson et al. (2004)
- Devarakonda and Olminsky (2004)

Present Work

- Better data
- Better property estimates
- More fluids

Properties - Overall View

- Reliable data are not available for many materials
- Estimates are made if a given property is known for one material in a family.
- If a method is known to work to estimate properties of a family of fluids, that method is used for other families too, based on the known data.

In some cases no data are known. Ex.: The following halides could not be evaluated

- BCl_3, BBr_3, BI_3
- $SiCl_4$, $SiBr_4$, SiI_4

Possible heat pipe fluids: Halides of Al, Bi, Ga, Sb, Sn, and Ti

Surface Tension Estimation

Reid, Prausnitz and Poling (1987) recommendation:

Based on corresponding states equation- critical properties and normal boiling point are known

First step: Calculate Q

$$Q = 0.1196\left(1 + \frac{\frac{T_{Boil}}{T_{Critical}}\ln(P_{Critical})}{1 - \frac{T_{Boil}}{T_{Critical}}}\right)$$

Surface Tension Estimation

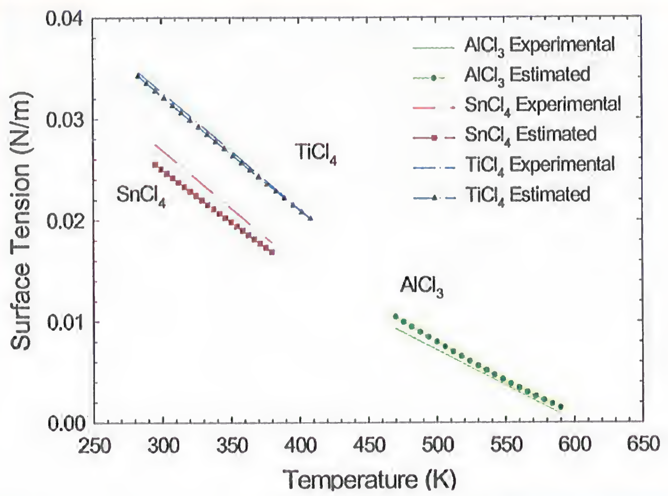
Second step: Calculate surface tension, σ

$$\sigma = Q\left(\frac{P_{Critical}}{Bar}\right)^{\frac{2}{3}}\left(\frac{T_{Critical}}{K}\right)^{\frac{1}{3}}\left(1 - \frac{K}{T_{Critical}}\right)^{\frac{11}{9}} 10^{-3}\,\frac{N}{m}$$

Better estimation is given by (authors):

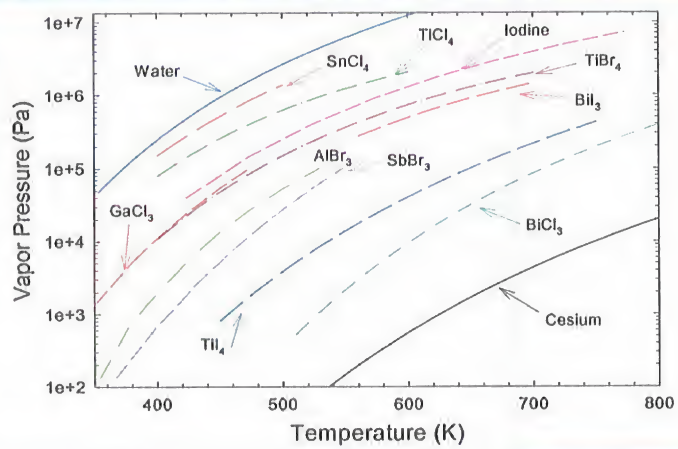
$$\sigma_{Halide} = \frac{2}{3}\sigma$$

Surface Tension



Vapor Pressure

Vapor pressure should not be too high or too low



Vapor Pressure

- Water heat pipe technologies are widely available. Hence, water is benchmarked as the high end
- Cesium vapor pressure is too low in this temperature range. Hence, it is considered as the low end.

The vapor pressures of all the fluids evaluated fall within this range.

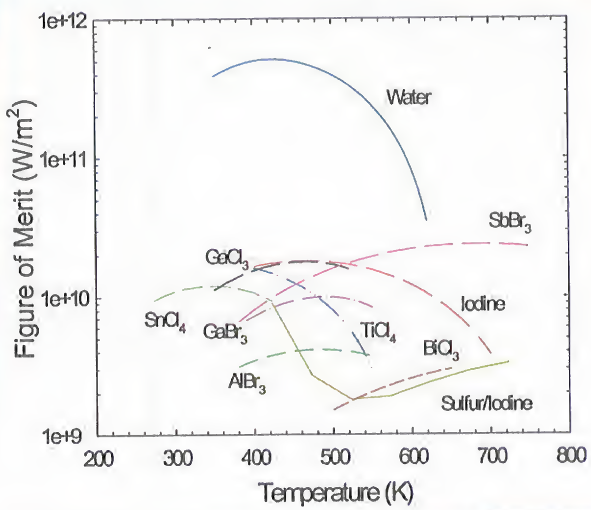
Figure of Merit

Definition of Figure of Merit (In Heat Pipe literature, also called, “Merit Number”, “Liquid Transport Factor”)

$$M = \frac{\rho_L \cdot \sigma \cdot \lambda}{\mu_L}$$

Merit Number, M, has those properties in the numerator whose values are desired to be higher and those desired to be lower in the denominator. Hence, the higher the value of the Merit Number, the better the fluid is thought to be for a heat pipe.

Figure of Merit

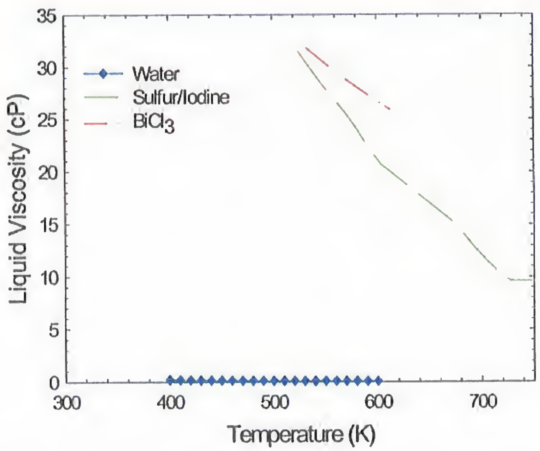


Some Promising Fluids

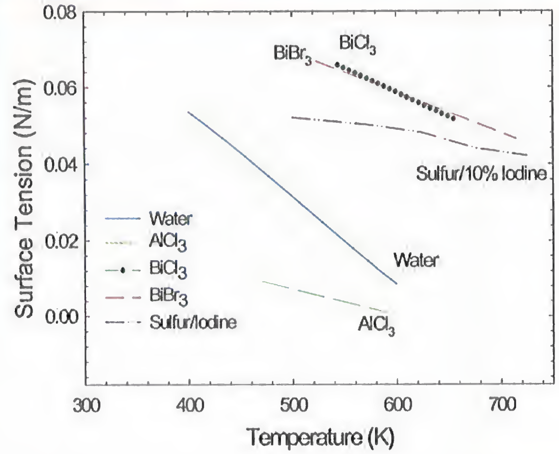
- Antimony Tribromide (Sb Br_3)
- Bismuth Trichloride (Bi Cl_3)

  High viscosity but compensated by high surface tension

Viscosity



Surface Tension



Materials Compatibility Testing at NASA Glenn

- Tests in progress

Al Br_3 with

Al 5052, Al 6061, Ti gr2

- Tests planned for the near future

Sb Br_3 with

Al and Ti

Summary

- Halides and some elemental materials evaluated for potential Intermediate Temperature Heat Pipes, 400 to 700 K.
- Properties estimated from known data wherever possible
- Not all possible fluids could be evaluated due to paucity of data
- Some materials identified as potential heat pipe fluids and for thermo-chemical compatibility testing with metals